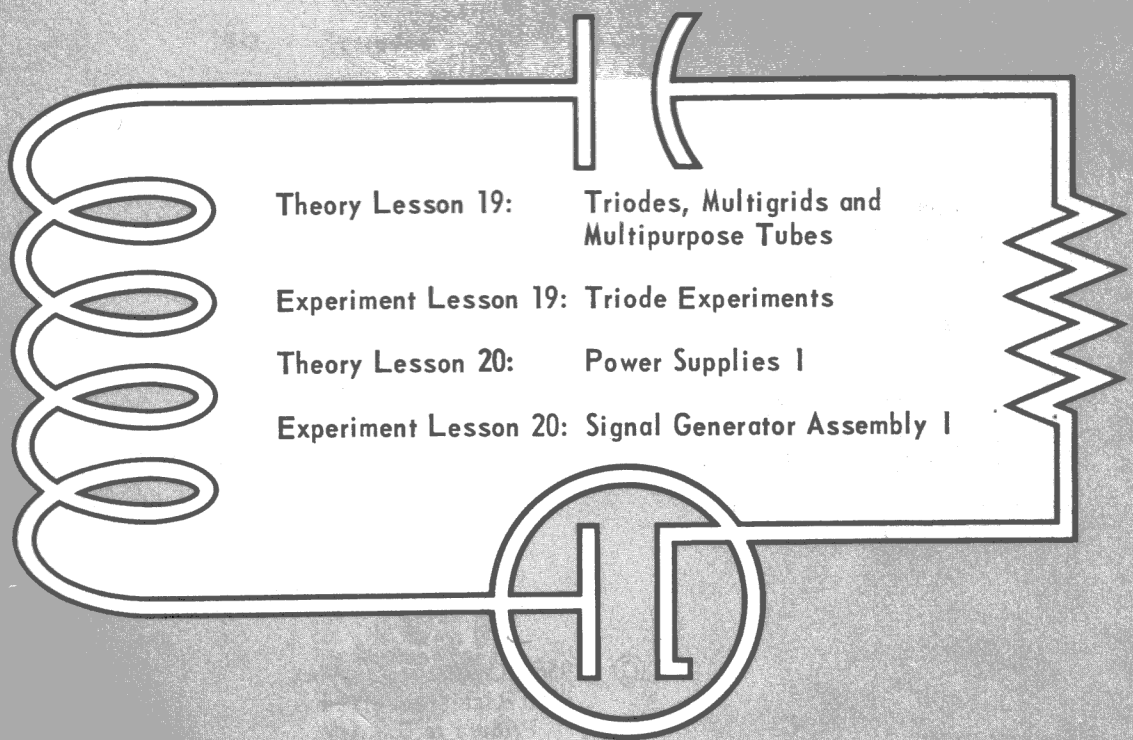
Study Group 10

ELECTRONIC FUNDAMENTALS



Theory Lesson 19:	Triodes, Multigrids and Multipurpose Tubes
Experiment Lesson 19:	Triode Experiments
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RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York, N. Y.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 19

TRIODES, MULTIGRIDS, AND MULTIPURPOSE TUBES

19-1. Triodes

19-2. Tetrodes

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RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

Theory Lesson 19

INTRODUCTION

In Lesson 17, you learned about the most simple type of electron tube — the diode. You know that the diode consists of two elements mounted inside a glass (or metal) shell from which nearly all the air has been removed to leave a partial vacuum. Either the cathode or the filament emits electrons when it is heated. These electrons are negative charges, so they are pulled across to the plate when the positive side of a battery is connected to the plate and the negative side of the battery is connected to the cathode. They cross the vacuum to the plate, through the battery, and back to the cathode, and form the plate current of the tube.

You know that some electrons hang in an invisible cloud in the space between cathode and plate. This forms the *space charge.* Since the space charge is negative, it repels the new electrons coming out of the cathode and interferes with their trip to the plate by slowing them down. Some electrons never get to the plate and simply become part of the space charge.

When we increase the voltage connected to the plate, making it more positive, it attracts more electrons from the space charge. The result is a higher plate current. Each time that the battery voltage is increased, the plate current rises a little higher. However, there is a limit to this effect. We finally reach a point where another increase in plate voltage has practically no effect on the plate current. This results in plate saturation, which means the voltage has reached the level needed to attract all the electrons that are emitted by the cathode. To get any further increase in plate current, we would have to increase the cathode temperature. For this reason, this condition is called temperature limiting.

You know, too, that the space charge limits the plate current. We can prove this by keeping the voltage between the plate and cathode constant and increasing the

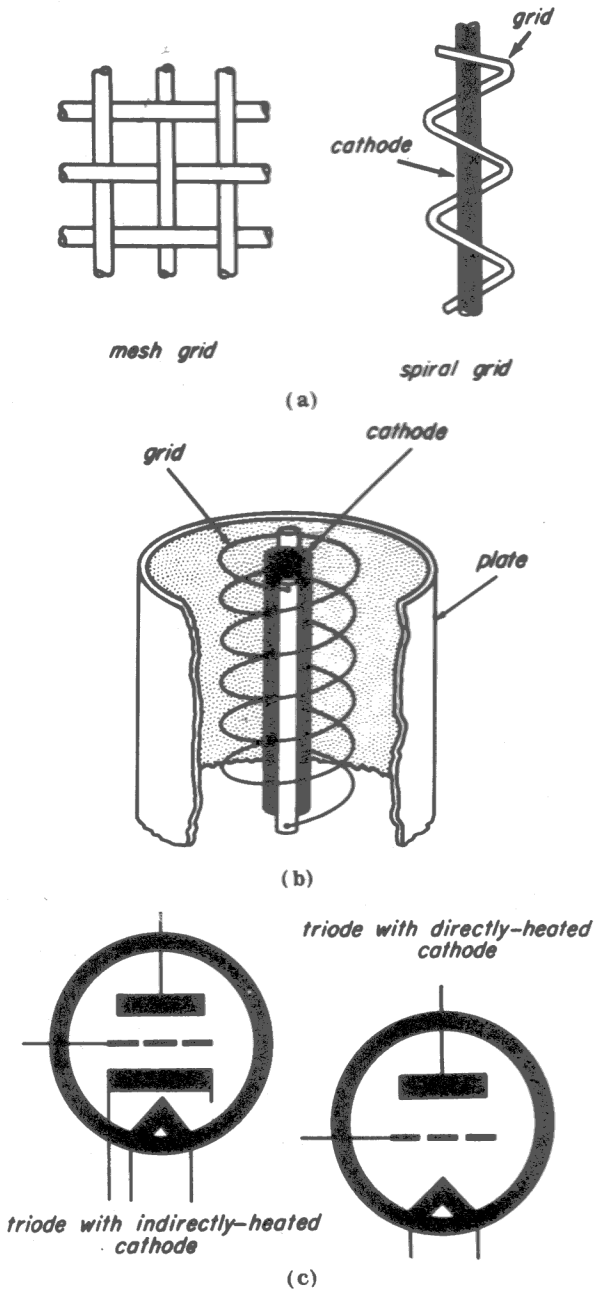
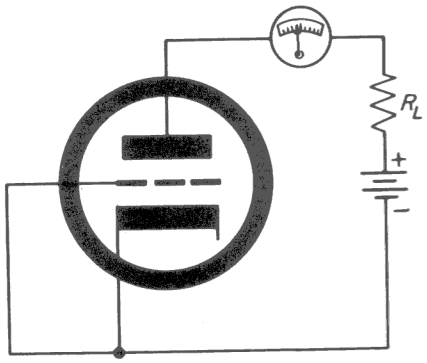
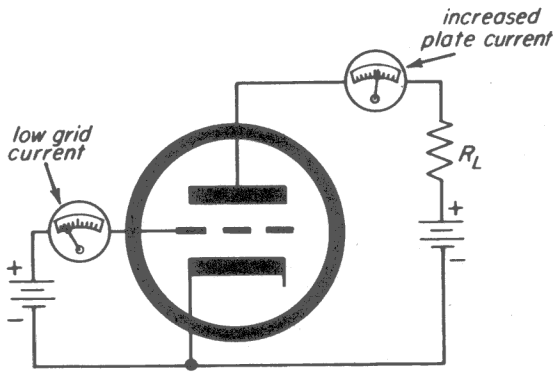


Fig. 19-1



grid at cathode potential

Fig. 19-2



positive charge on grid

Fig. 19-3

cathode temperature. As the cathode temperature rises, the plate current rises until a point is reached when further increase in cathode temperature has little or no effect on the plate current. We call this point voltage saturation.

The basic principles of diode operation apply to triodes, tetrodes, and other tubes that you will now study.

19-1. TRIODES

The word *triode* means three-element or three-electrode. Two of these elements are the cathode and plate. The third element is called a *grid*. A grid is an open mesh or coil of wire, as shown in Fig. 19-1*a*. It is placed between the cathode and the plate (Fig. 19-1*b*). It is made so that the electrons may pass easily between the turns of wire or the openings in the mesh as they travel from the cathode to the plate. The schematic symbols for directly and indirectly heated cathodes are shown in Fig. 19-1*c*.

The grid has an important effect on electron flow through the tube. It controls the flow of plate current without varying the plate voltage or the cathode temperature. For this reason, it is often called the *control grid*. Let's see how the grid controls plate current. To do this, we connect the triode circuit as shown in Fig. 19-2. Notice that there is a load resistor in the plate circuit, such as we used for the diode. You remember that the plate current flowing through the load resistor produces a voltage drop that we can take off and use. In the same circuit we have a milliameter for measuring plate current and a battery connected so that the plate is positive with respect to the cathode. And, finally, we tie the grid to the cathode so that they are both at the same potential.

With this setup, electrons emitted by the cathode find the grid at the same potential and slip easily through the spaces between grid wires. A few electrons crash into the grid and stay there. Once beyond the grid, the positive plate attracts them strongly and they travel through the space charge to reach it. The result is a flow of plate current, measured by the milliameter, that is about the same that we would expect from a diode. Therefore, the grid has practically no effect when it is connected directly to the cathode.

Now, let's try placing the grid at a different potential from the cathode. We can do this by connecting a small battery between the cathode and grid, as shown in Fig. 19-3. We will connect the positive side to the grid and see what happens.

This time electrons thrown out of the cathode find a positive charge right ahead of them because the grid is a few volts more positive than the cathode. The electrons are travelling fast when they leave the cathode, and the positive grid speeds them up still more. Some of them, those passing nearest to the grid wires, will be pulled into the grid. However, because of the positive attraction of the plate, most of them fly between the grid wires. On the other side, they keep going toward the plate. The fact that the grid is positive helps to cancel out part of

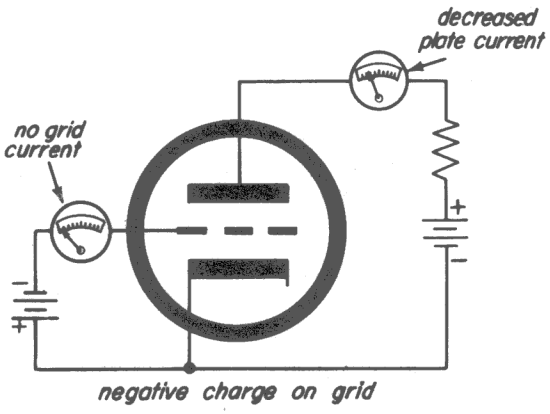


Fig. 19-4

the negative space charge. Thus, the electrons that get past the grid find it much easier to reach the plate.

We see that the meter shows that a higher value of plate current flows as a result of making the grid positive. (There is also a small current in the grid circuit due to those electrons that are attracted by the grid.) A positive grid increases the plate current by making it easier for electrons to travel through the tube.

Our next step is to reverse the battery in the grid circuit, making the grid more negative than the cathode, as in Fig. 19-4. Electrons leaving the cathode find a charge ahead of them that is more negative than the cathode. Even though they are travelling at a high speed, this negative charge on the grid immediately begins to repel the electrons and they are slowed down. However, some of the electrons are travelling fast enough to coast through the spaces between the grid wires in spite of the negative charge. Once through, the positive plate attracts them and they begin to pick up speed again, although they must still get through the negative space charge.

Many other electrons, however, are slowed down and stopped by the negative grid potential. A number of these remain in the space charge, and make it harder for other electrons to get through. Still others fall back into the cathode.

The meter in the plate circuit now shows a low value of plate current. The negative grid decreases the plate current by adding to the effect of the space charge, so that fewer electrons are able to get through to the plate. Because the grid is negatively charged, the electrons are repelled by it and no grid current flows.

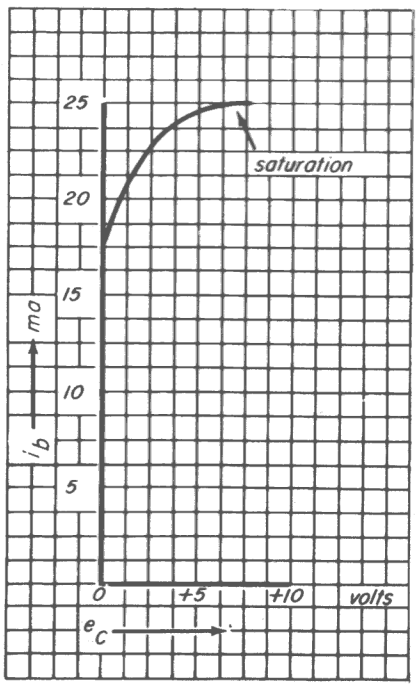
The small battery that we have connected between grid and cathode gives us what is called the *bias voltage*, or, simply, the *bias*. We do not have to use a battery, of course, to get this small, steady voltage — it can be obtained from a power supply or by any of several methods, which are discussed completely in a later lesson. The important thing is that we can control the amount of plate current flowing *without changing the plate voltage*, just by making the grid a few volts more positive or more negative than the cathode. The bias is usually, but not always, arranged to make the grid more negative than the cathode.

So far we have discussed only the effect of making the grid a little positive or negative. Suppose we see the effect of increasing values of positive bias. Starting out with no grid bias (the grid connected to the cathode), the tube acts like a diode. Plate current than depends entirely upon the amount of plate voltage we use. Without changing the plate voltage, we put a small positive bias on the grid and find that the plate current immediately begins to increase, as shown in Fig. 19-5*a*. As we build up the value of positive bias, more and more plate current flows, as indicated by the steadily rising curve.

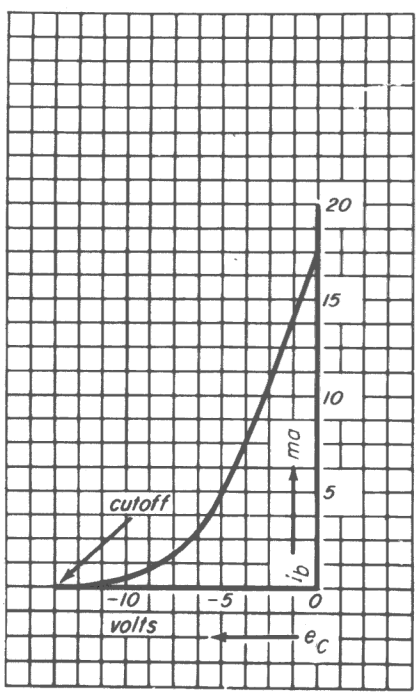
Before long, however, the curve begins to flatten out. Finally, we reach a point where any further increase in the positive voltage on the grid does not cause any measurable increase in plate current. This is the saturation point of the triode at whatever voltage we have on the plate. (Remember, we said that the plate voltage would remain the same.)

Now, if we go back to the point where there is no (zero) bias on the grid and begin applying various negative bias voltages, we get the effect shown in Fig. 19-5*b*. Again, a certain value of plate current flows with zero bias. Then as we apply a small negative bias, we find that the plate current drops somewhat because we are making it

harder for electrons to flow through the tube. As we make the bias more and more negative, the plate current decreases. The pointer of the milliameter we connected in the plate circuit drops down toward zero. Soon a value of negative bias is reached where the meter reads zero. The grid is then so negatively charged that none of the electrons emitted by the cathode can get past the grid and reach the plate, so no plate current flows. We say that the tube is *cut off*, and the value of negative bias that does this is called the *cut-off bias*. If we make the grid more negative nothing happens; but if we make it even a fraction of a volt more positive, a little plate current will flow.



(a)



(b)

Fig. 19-5

Actually, the two curves in Fig. 19-5 are simply two parts of one curve that shows how the voltage on the grid varies the plate current, provided the plate voltage is not changed. These two parts are put together in one curve in Fig. 19-6. This is the i_b-e_c curve, or the transfer characteristic curve of this triode.

Up to this point we have talked about the triode with nothing but d-c voltages applied to it, even though we have varied the bias voltage on the grid to make it positive or negative. Signal voltages in radio and television sets are mostly a-c voltages, so let us apply a.c. to the triode.

One way to do this is to apply an a-c signal between grid and cathode (as shown in Fig. 19-7). When an alternating signal voltage is applied, the voltage on the grid becomes

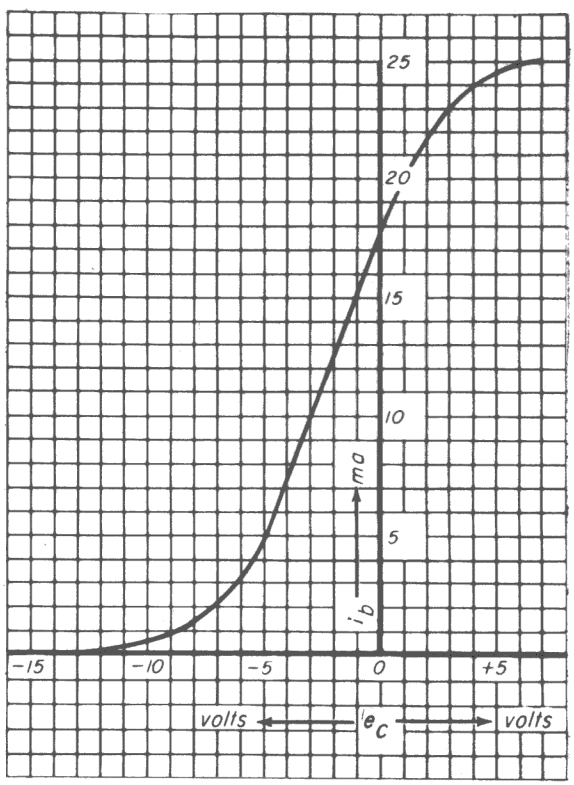


Fig. 19-6

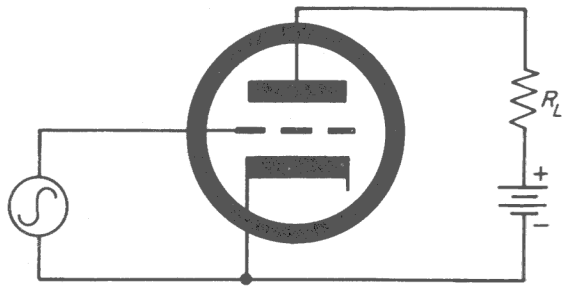


Fig. 19-7

alternately positive and negative with respect to the cathode. Sometimes, in order to show how one factor changes as another factor is varied, we draw the graph of each one above the other and use the same time base for both. For example, in Fig. 19-8, the grid voltage (e_c) graph is drawn immediately above the plate current (i_b) graph. The vertical axis of the grid-voltage graph is marked off in volts and that of the plate current is marked off in milliamperes. However, they both use the same time units; the vertical lines that mark off the quarter cycles are the same for both. Therefore, we can tell how the change of plate current between zero and the first quarter cycle compares with the change in grid voltage during the same period. We can see at a glance that as the grid voltage changes, the plate current changes in a like manner. As the grid becomes more and more positive (on the positive half cycle), the plate current increases. As the grid voltage becomes less positive, the plate current decreases and, when the grid voltage changes polarity and becomes negative, the plate current still decreases. We can see that they keep in step with each other throughout the

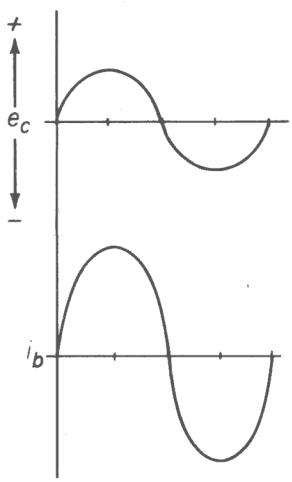


Fig. 19-8

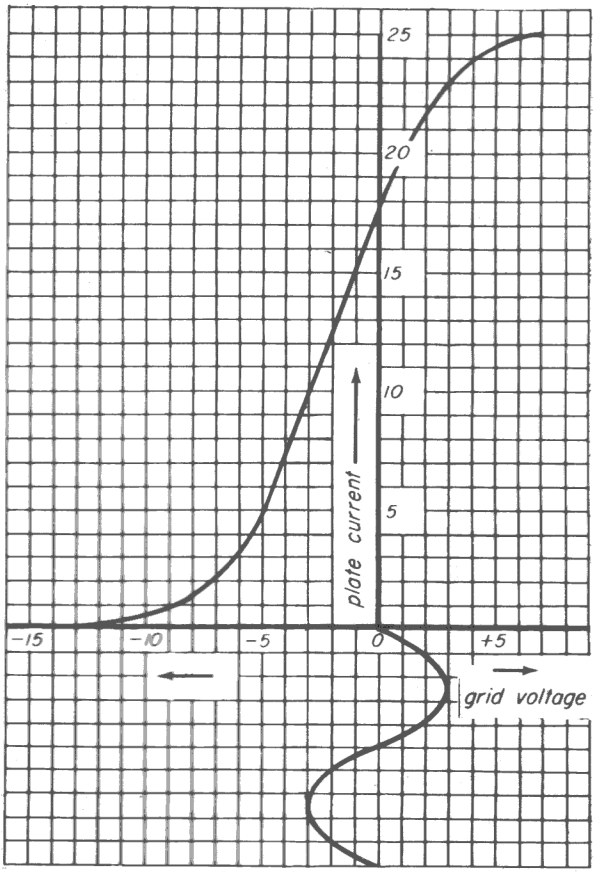


Fig. 19-9

complete cycle: that the waveform of the grid voltage and the waveform of the plate current are alike and are in phase.

Look again at Fig. 19-6. Note that the horizontal axis is marked off in voltage values that increase to the left and right of the zero line. The voltages to the left of zero are negative and those to the right of zero are positive. If an a-c voltage with a peak value of three volts is placed across the grid resistor of a tube with such a characteristic curve, the grid voltage would swing from zero to plus 3 volts and back through zero to minus 3 volts. This would make a total change of 6 volts on the grid for each cycle, as shown in Fig. 19-9.

You will see many graphs similar to that shown in Fig. 19-9. Now is a good time to learn how to read and understand one. The characteristic curve is the same that you saw in Fig. 19-6. Only one new thing has been added: a sine-wave signal has been applied to the grid. However, before the signal was applied, the grid and the cathode were

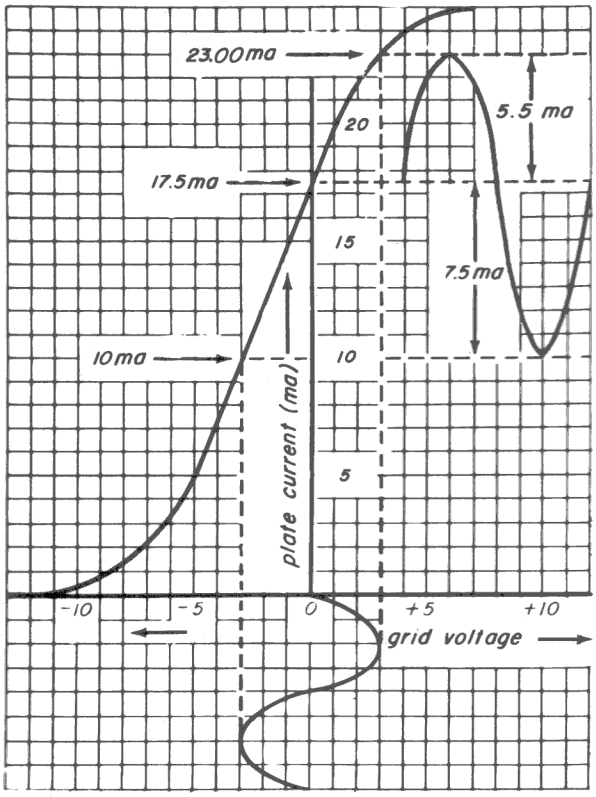


Fig. 19-10

at the same potential. In other words, we can say that, without a signal, the grid potential (with respect to the cathode) is zero volts. So, when the signal is zero, the grid voltage is zero — as shown in the graph. However, as the signal voltage rises from zero to its positive maximum value, the grid voltage changes from zero to +3 volts. Then, as the signal voltage drops from its maximum positive value and returns to zero, the grid drops in value from +3 volts to zero. As the signal voltage changes from zero to its negative peak, the grid voltage swings from zero to −3 volts. Finally, the signal voltage returns from its negative peak to zero and the grid voltage swings from −3 volts to zero.

The 6-volt change in grid voltage produces a change in plate current. Let's see what this plate current change is. First we erect a perpendicular line from the −3-volt point and the +3-volt point on the horizontal axis until each meets the tube characteristic curve (Fig. 19-10).

Then, from each point where a perpendicular meets the characteristic curve, we draw a line horizontally to the vertical axis. We also draw a horizontal line through the point, where the I_b curve meets the zero axis. Looking at the result, we find that the plate current changes from 17.5 ma to 23.0 ma and back to 17.5 ma when the grid voltage is positive; while during the period that the grid is negative, the current falls from 17.5 ma to 10 ma and then rises again to 17.5 ma. The total current swing is from 10 ma to 23.0 ma for a total of 13.0 ma. However, please note that the plate current change during the positive half cycle of the grid is 5.5 ma and during the negative half cycle is 7.5 ma. Note, too, that the current curve tends to flatten off during part of the positive grid swing because the current reaches the knee (curved section) of the characteristic curve. Therefore, the plate-current waveform does not follow the grid-voltage waveform for the complete cycle but distorts it during part of the period of the positive grid-voltage swing. This presents us with a problem: how may we avoid distorting the current waveform?

To find the answer to our problem, let's take another look at the tube characteristic curve. Note that it is linear (straight) between points A and B on the curve in Fig. 19-11*a*. Between these two points, equal changes in grid voltage produce equal changes in plate current. If we can operate from the −2-volt point on the horizontal axis, as in Fig. 19-11*b*, we can produce a 6-volt grid swing to produce a 15-ma plate current swing, with equal current changes above and below the operating point. We can solve our problem if we apply our 6-volt peak-to-peak signal voltage to the grid when it is already negative by two volts. This can be done by making the grid two volts negative with respect to the cathode. So we insert two volts between the grid and the cathode, as in Fig. 19-12. This produces an operating point of −2 volts on the grid. We say that the grid bias is −2 volts. We sometimes write it this way:

$$E_c = -2 \text{ volts}$$

This makes it possible for us to tell the grid bias voltage from the signal voltage.

Look at Fig. 19-11*b* again. Note that when the signal voltage is zero, the only voltage on the grid is the −2 volts of d-c bias. When the signal swings positive, it

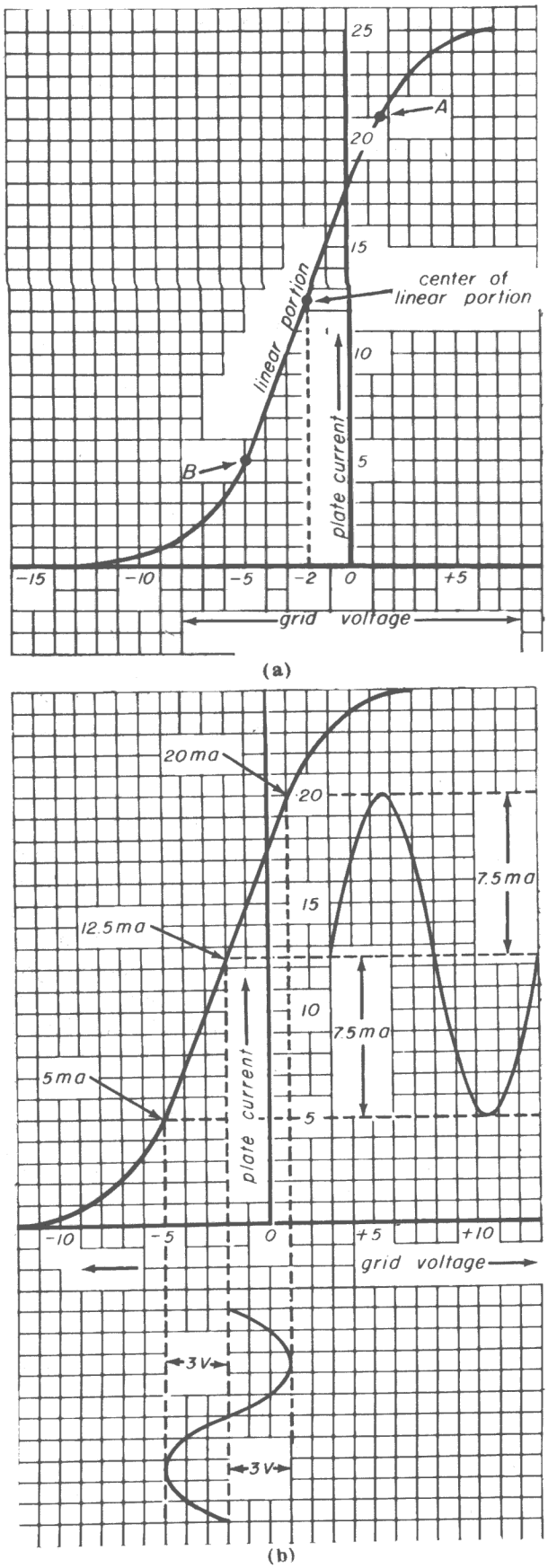


Fig. 19-11

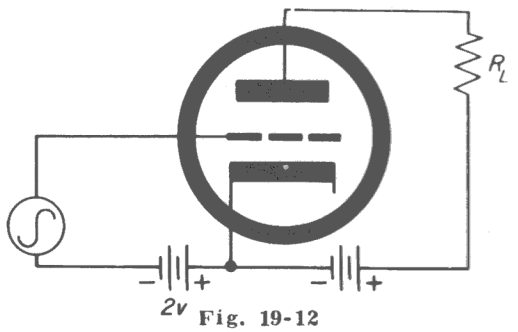


Fig. 19-12

opposes the d-c bias voltage so that the voltage on the grid changes from –2 volts to +1 volt. When the signal swings negative, it adds to the d-c bias and causes the grid voltage to change to –5 volts. The current changes produced by the grid voltage changes are found by extending vertical lines up to the characteristic curve, as shown.

Now, let's make the bias greater and see what happens. Suppose that we use a grid bias of –5 volts and apply the same signal voltage. Figure 19-13 shows that when a 6-volt peak-to-peak signal is applied to the grid biased at –5 volts, the plate current waveform is distorted during the negative half cycle of the signal. This distortion is due to the fact that the tube is operating in the curved portion of the characteristic curve during the second half cycle. Also, distortion may result if grid current flows, even when operating on a linear part of the curve. Grid current flows whenever the grid is positive with respect to the cathode. *Thus, the bias is usually made at least as negative as the peak signal voltage*, so that the grid is not driven positive. So, you can see that too much bias or too little bias may cause distortion in the plate-current wave-form. Therefore, the effect of the proper bias voltage is to provide an operating point from which the signal voltage applied to the grid produces linear changes in plate current without distorting the plate-current waveform.

Voltage Output. Changes in plate current caused by the signal voltage applied to the grid do not do us much good unless we use them to produce voltage changes in the plate circuit. These plate voltage changes are produced by the plate current flowing through the plate-load resistor, such as the 5,000-ohm resistor shown in Fig. 19-14*a*.

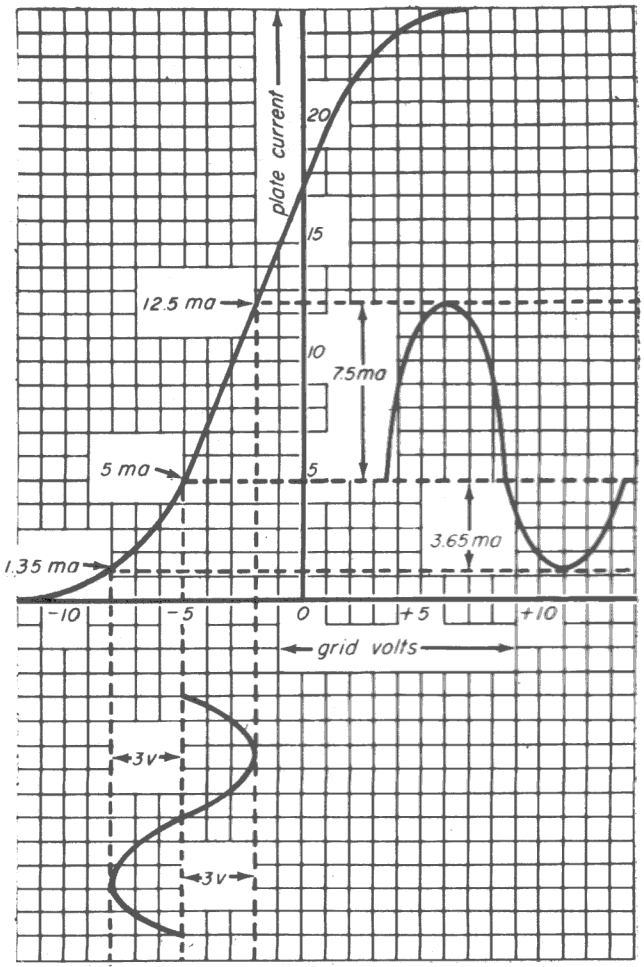


Fig. 19-13

Look at the graphs in Fig. 19-14*b*. Note that three variable factors, e_c, i_b, and e_b, are plotted, one above the other, using the same time base (as was done in Fig. 19-8). The level line at the beginning of each curve represents the condition when no signal voltage is applied to the grid. For example, the level line at the beginning of the e_c curve represents the grid voltage when there is no signal, when only the bias is applied to the grid. The graph shows that, when the signal voltage is zero, the plate current I_b is 12.5 ma. The voltage drop across R_L may be found by using Ohm's law:

$$E_{RL} = I_b \times R_L$$

$$= 0.0125 \times 5{,}000$$

$$= 62.5 \text{ v}$$

If the plate-supply voltage (E_{bb}) is 250 volts, as shown, then the voltage at the

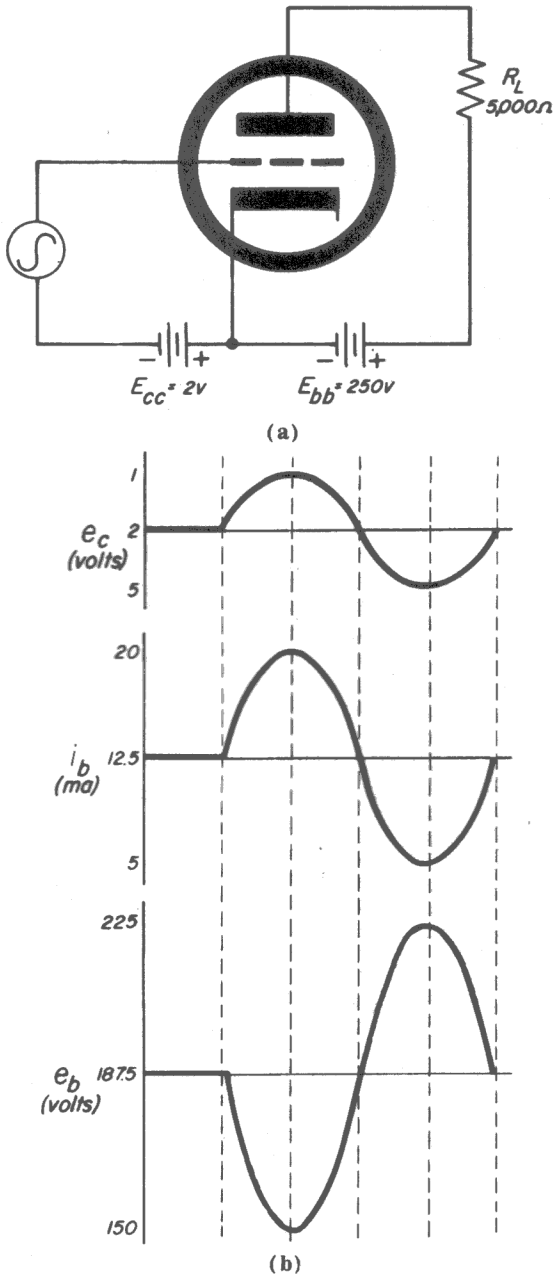


Fig. 19-14

plate (e_b) equals the supply voltage less the voltage drop across R_L, 250–62.5 or 187.5 volts. This is the no-signal plate voltage, represented by the level line at the beginning of the e_b curve. When the signal voltage swings the grid positive to +1, the plate current becomes 20 ma. This produces a voltage drop across R_L of 100 volts and makes the plate voltage 250 less 100, or 150 volts. When the signal swings the grid negative to –5 volts, the plate current becomes 5 ma, the voltage drop across R_L becomes 25 volts, and the plate voltage becomes 225 volts.

Look at Fig. 19-14*b* again. Note that a change of 6 volts in grid voltage produces a change in the plate of 75 volts. A small change in grid voltage produces a large change in plate voltage. We say that the signal is *amplified* and the process is called *amplification.* Note that while the grid voltage and plate current are in phase, the plate voltage is 180 degrees out of phase with either. Note, too, that the maximum voltage drop across the plate load resistor is 100 volts and the minimum is 25 volts, so the voltage change across it is the same as the change in plate voltage. So the amplified signal voltage may be taken off the plate-load resistor. And, finally, note that the plate-voltage waveform is the same as the grid-signal-voltage waveform (except that it is amplified and is 180 degrees out of phase). So, by selecting a proper grid bias so that the tube operates in the linear portion of its characteristic curve, we get an undistorted plate-voltage waveform as well as an undistorted plate-current waveform.

One important point to remember, however, is that the proper value of grid bias depends on the value of plate voltage. The characteristic curve that we have been studying was plotted for a triode whose zero-signal plate voltage is 187.5 volts. For any plate voltage greater or less than this amount, a new characteristic curve must be plotted and the proper grid bias be selected, as you shall see in later lessons.

Even though we get a greater voltage out of the triode than we put in, we do not get something for nothing. The power that is required to amplify the signal voltage comes from the battery or power supply that provides the plate voltage. But the fact that we can amplify a signal without changing it means that we can take very weak signals from a radio or television antenna and build them up to a useful strength without losing or changing the words, music, or picture that they contain.

Interelectrode Capacitance. There is another fact about triodes that you should know. There is capacitance between the different elements of the tube, which is called

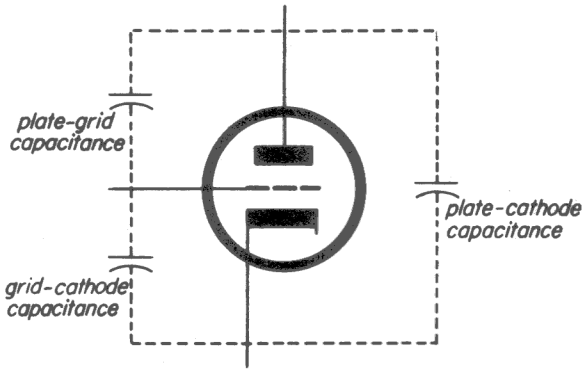


Fig. 19-15

interelectrode capacitance. You know that capacitance exists between any two pieces of metal that have a dielectric between them. In the triode, a metal cathode, grid, and plate are separated by a vacuum, which makes a good dielectric. In the base of the tube, the leads from the electrodes are brought out through the glass envelope — and glass is also a dielectric. As a result, there is a very small but definite capacitance between each electrode and the other two. The effect is the same as if actual capacitors were connected to the triode, as shown in Fig. 19-15. There is capacitance between plate and grid, and between grid and cathode. The interelectrode capacitance values for a typical triode, the 6J5, are as follows.

Grid to plate	3.4 $\mu\mu$f
Grid to cathode	3.4 $\mu\mu$f
Plate to cathode	3.6 $\mu\mu$f

As you know, capacitance permits a-c voltage to pass. The higher the frequency, the more easily the voltage is passed. At low frequencies, the reactance is so high that very little a.c. passes. So, in audio circuits, interelectrode capacitance is not often important. But, at radio frequencies, the plate-to-grid capacitance in a triode begins to cause trouble. Some of the r-f voltage passes from the plate back to the grid because of the grid-to-plate capacitance. We call this *feedback.* In most r-f amplifier circuits, this feedback voltage adds to the signal voltage and is amplified by the tube. This produces a greater amount of amplified signal voltage in the plate, which causes the grid-to-plate capacitance to feed back even

more voltage to be amplified and fed back again. This vicious cycle builds up the signal voltage on the grid to the place where the tube loses control and operates outside of the linear portion of the characteristic curve, which causes squealing and other forms of distortion.

When you study later lessons about oscillators, regeneration, and degeneration, you'll see how we use interelectrode capacitance to produce certain operating conditions in the tube that we want. But in most r-f amplifiers, we find that interelectrode capacitance produces effects that we do not want. So, we reduce the feedback by adding another element.

The plate-to-cathode capacitance does not ordinarily give any trouble, and the grid-cathode acceptance is relatively harmless until we reach ultra-high frequencies (uhf). At these frequencies, the effects of all the interelectrode capacitances become so serious that ordinary triodes are useless, and special uhf tubes are required.

19-2. TETRODES

When we add a fourth element to the three we have been discussing, we have a *tetrode*. The chief reason for adding this fourth element is to get rid of the undesirable feedback across the plate-grid capacitance of the triode. The new element is another grid, placed between the control grid and the plate, as shown in the cutaway view of Fig. 19-16*a*. It is called the *screen grid*, and its job is to act as a shield between the control grid and plate, cutting the plate-grid capacitance down to practically nothing. The tetrode is shown in schematics as in Fig. 19-16*b*, and in tube manuals as in Fig. 19-16*c*. When a tube has more than one grid, each grid is numbered in order, starting from the grid nearest the cathode. So, the control grid is identified in the tube manuals as $G1$ and the screen grid as G_2.

We now have a control-grid to screen-grid capacitance and a screen-grid to plate capacitance, but these give us no particular trouble, since the screen grid is usually grounded through a capacitor. Any voltage

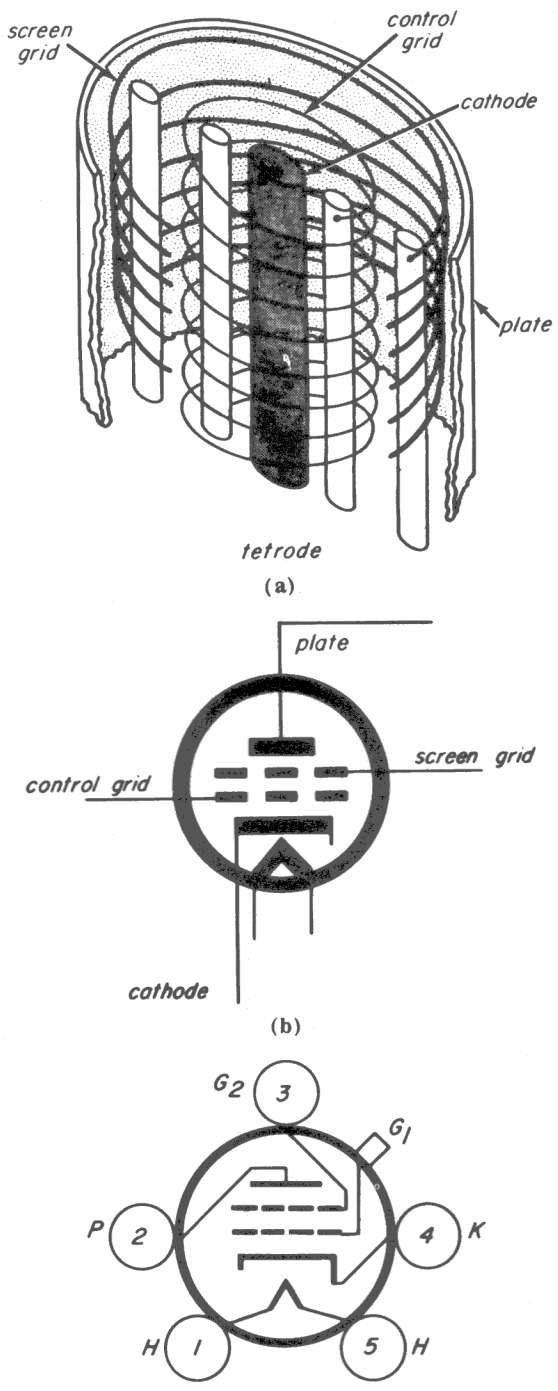


Fig. 19-16

fed back from the plate circuit goes to ground, not to the control grid, so it cannot disturb the operation of the tube as it does in the triode.

The screen grid also has another important effect. Since it is a shield between the other electrodes and the plate, the plate voltage variations have practically no effect on the

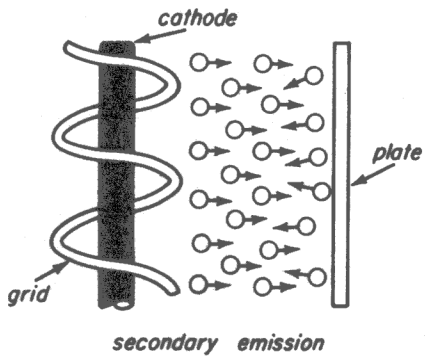


Fig. 19-17

flow of electrons through the tube. To get electrons to the plate, we must have a fairly high positive screen grid voltage (that is, less than the plate voltage). Then, electrons leaving the cathode are attracted to the screen grid. By the time they get there, however, they are travelling at very high speeds, and most of them shoot right through the big spaces between the screen wires. Once the electrons are beyond the screen, the plate offers a stronger positive attraction, so the electrons continue until they strike the plate. Some electrons do hit the screen, so a small current flows in the screen-grid circuit.

Because the screen grid pulls the electrons from the cathode toward the plate, the plate current in the tetrode depends mostly upon the screen voltage and very little upon the plate voltage. This makes it possible to get higher amplification with the tetrode than with the triode, and we get it without the plate-to-grid feedback.

There is one troublesome effect in a tetrode, however, that we do not find in the diode or triode. Whenever electrons moving at very high speeds strike the plate, they knock a number of other electrons out of the metal and into the space (Fig. 19-17). We call it *secondary emission*. It occurs in all electron tubes, but in diodes and triodes it does not cause trouble because there are no other positive electrodes nearby to attract the secondary electrons. They are simply pulled back to the plate.

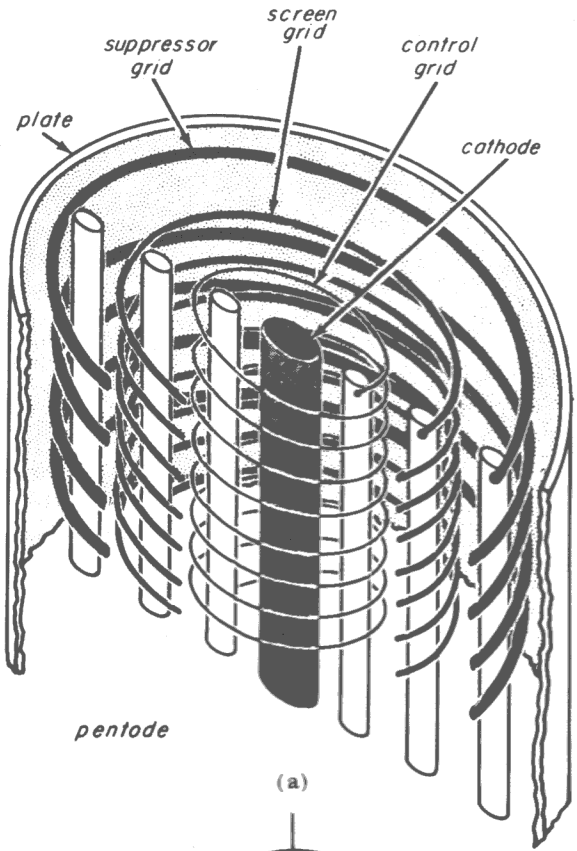
In the tetrode, it is a different story. The positive screen grid is not far from the plate, and it tends to attract some of the secondary electrons. If the plate voltage swings down lower than the screen voltage, the screen attracts practically all of the secondary electrons. This results in a current flowing in the opposite direction from the normal electron flow through the tube. Therefore, the plate current is reduced, rather than increased when the plate voltage drops. In other words, we're limited in the amount of plate voltage swing we can permit, yet high amplification produces large swings in plate voltage. The solution to this problem is in adding another electrode, which leads us to the next group of tubes.

19-3. PENTODES

The five-element tube is called a *pentode*. The fifth electrode is another grid, called the *suppressor* grid (G_3), placed between the screen and the plate. The pentode is illustrated in Fig. 19-18. The suppressor grid is usually connected to the cathode, sometimes inside the tube, sometimes by a connection outside the tube, which makes it negative with respect to the plate. Now when secondary emission occurs, the secondary electrons knocked out of the plate find a negatively charged electrode, which turns them around and drives them back to the plate again.

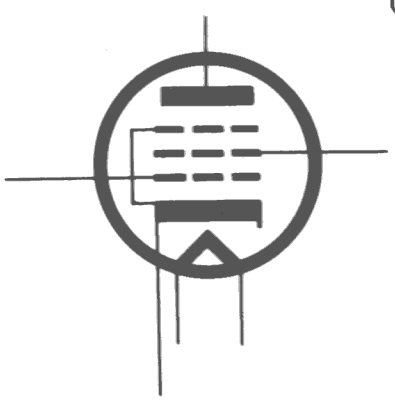
With the suppressor to stop the bad effects of secondary emission, there's practically no interference with normal plate-current flow. The plate voltage in a pentode, as in a tetrode, has little effect on the plate current. Therefore, high amplification is possible, since there is no limitation on large plate-voltage swings. The plate voltage in a pentode can swing lower than the screen voltage without seriously interfering with normal operation.

In both tetrodes and pentodes, the control grid controls the plate current in just about the same manner as in triodes. Pentodes are widely used as amplifiers for radio and audio frequencies. Those made for use in r-f amplifier circuits are designed to produce a large increase in voltage for a given input signal voltage and are called *voltage amplifiers*. Those made for use in audio amplifiers are designed to produce enough output power to operate a loudspeaker and are called *power amplifiers*. In these tubes, the screen is not used so much to shield the grid from the plate as to give an extra pull to the elec-



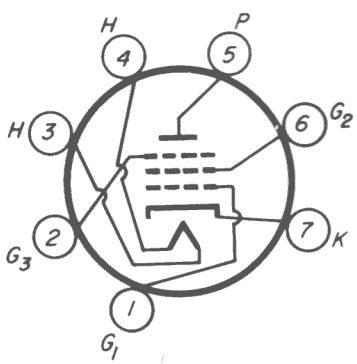
pentode

(a)



schematic symbol

(b)



tube-manual symbol

(c)

Fig. 19-18

trons. This helps to draw heavy plate current with fairly low plate voltages, giving high amplification of power.

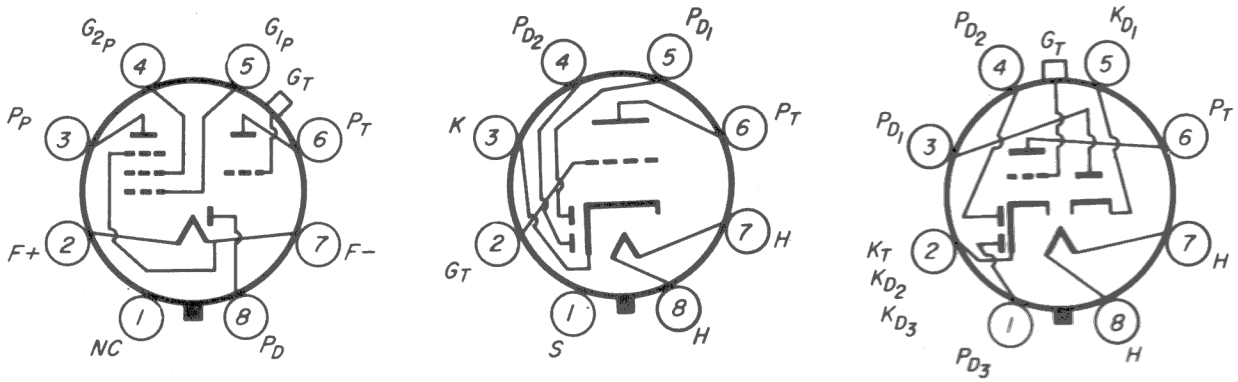
19-4. MULTI-ELEMENT AND MULTIPURPOSE TUBES

Back in the early days of radio, there were only a few types of tubes, and a single type was often used for all the circuits in a set. One type of triode, for example, might be used in the r-f, i-f, and a-f amplifier circuits, as well as in the oscillator and detector circuits. Since all of these circuits have somewhat different requirements, a single type of triode could not meet them all efficiently.

Today, tube types have been designed to do one kind of job and do it as well as possible. A modern tube made for r-f amplification will do a fine job in its r-f circuit, but would be of little use as an audio output tube. Tubes are also designed with two or more tube types in the same glass bulb or metal shell, thus cutting down on the number of tubes in a radio or television set. These are called *multipurpose* tubes. Figure 19-19 shows the schematic symbols of typical multipurpose tubes.

Among the tube types designed for special jobs are those called the *multi-element* or *multigrid* tubes, which may have up to five or more grids to give certain characteristics in operation. Some, for instance, enable us to control the plate current by means of two separate signals applied to two different grids. Common examples of the multi-element tubes such as the *pentagrid converter* types 6SA7 and 6BE6, and the pentagrid mixer type 6L7 are shown in Fig. 19-20.

Notice that there are two screens, tied together inside the tube. Each screen shields one of the signal grids from the plate. One screen also shields the two signal grids from each other. The suppressor may be connected to the cathode either internally, as in the 6L7 and 6BE6, or externally, as in the 6SA7. In ordinary use in superheterodyne receivers, the r-f signal voltage is applied to the signal grid and an r-f sine-wave voltage from an oscillator circuit is applied to another grid.



1D8-GT (a). 6SQ7 (b) 6S8-GT (c)

Fig. 19-19

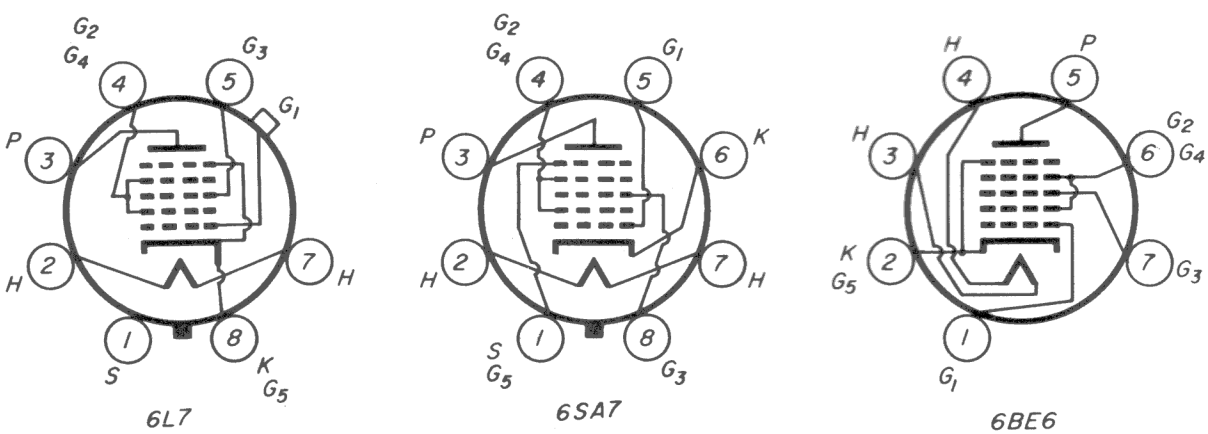
Thus, the plate current is varied at two different frequencies and the i-f signal is obtained from the mixture. These circuits are discussed completely later in the course.

19-5. GAS-FILLED TUBES

You will recall that we discussed two types of gas-filled diodes back in Lesson 17. These were the *mercury-vapor* and the *cold-cathode* rectifiers.

In both types of tube, the electrons flow from cathode to plate through a gas, rather than a partial vacuum as in ordinary tubes. The electrons, travelling at high speeds, as usual, smash into atoms in the gas molecules. Each of these collisions knocks an electron out of the molecule, and this electron is immediately pulled toward the plate, joining the main stream of electrons from the cathode. It may strike another gas molecule on the way, releasing still another electron, etc.

Another important gas-filled tube is the *thyratron*. This is usually a triode with a heated cathode, such as that in Fig. 19-21. If we connect the grid to the cathode, the tube operates like any mercury-vapor diode. When the plate voltage reaches the firing point, a small current starts to flow. The electrons crash into the gas atoms, releasing more electrons, and a heavy plate current builds up quickly. Ionization does not happen instantly; it always begins with a *few* electrons hitting a *few* gas atoms and increases to a great many hit-and-run collisions. The whole process builds up in a few thousandths of a second, but the small current that flows when the firing voltage is first reached is necessary in all gas-filled tubes to get the ionization started. It is called the *starting current*.



6L7 (a) 6SA7 (b) 6BE6 (c)

Fig. 19-20

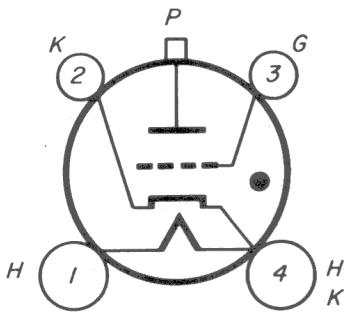


Fig. 19-21

If we put a negative bias on the grid of the thyratron, it becomes more difficult for plate current to flow, just as in an ordinary triode. This means we must raise the plate voltage to a *higher* value in order to get the starting current to flow. Thus a negative bias raises the firing point. If we put a positive voltage on the grid, plate current can flow more easily, so a much lower plate voltage will fire the tube.

The bias we put on the control grid of the thyratron varies the firing point. This means that we can set the thyratron to fire at any desired plate voltage between certain upper and lower limits, by using a fixed bias. Or we can use a fixed plate voltage and vary the grid voltage. The tube will fire only when the grid voltage rises to a certain value.

There is an important difference between the thyratron and an ordinary triode, however, *The thyratron grid cannot control plate current after the tube fires and ionization begins*. From this point on, we get a high plate current and the tube acts like any gas-filled diode. When the plate voltage drops to the de-ionizing value, the tube stops conducting and the grid again takes control.

Since the thyratron handles heavy currents and can be turned on and off when we wish, it is widely used as an *electronic switch*, to take the place of mechanical switches or relays in automatic equipment.

19-6. ELECTRON-RAY TUBES

Another type of tube that has a special purpose is the *electron-ray* tube. This type of tube, sometimes called a Magic Eye® is

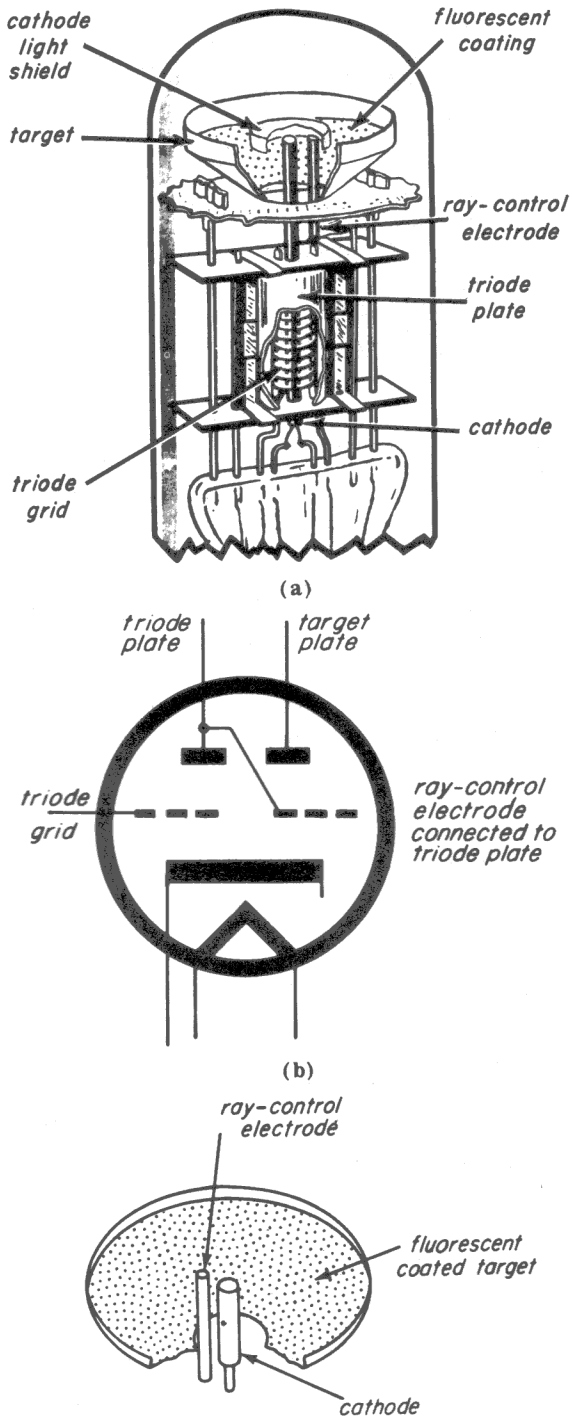


Fig. 19-22

used as a tuning indicator in radio receivers and as a null (zero) indicator in test equipment. It consists of a triode section, a cone shaped plate called a *target*, and a *ray-control electrode* (Fig. 19-22*a*). The ray-control electrode, shown in schematic form (Fig. 19-22*b*), is drawn like a grid. It is actually a wire that is run parallel with the cathode,

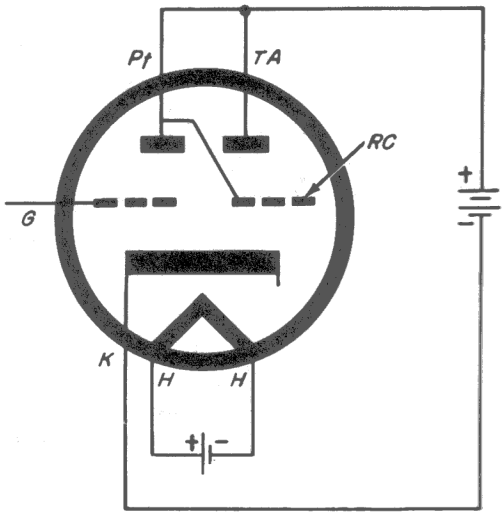


Fig. 19-23

and stands between it and the target plate (shown in Fig. 19-22*c*). The inner surface of the target has a coating of what is called a *fluorescent* material, which only means that it is a material that gives off light (such as is on the face of the picture tube of a television receiver). When the target is struck by an electron emitted by the cathode, the fluorescent coating gives off a dull green light at the point where it is struck. A ray-control is normally mounted so that the target plate faces the viewer (Fig. 19-22). When electrons strike all sections of the fluorescent coating of the target, a circle of dull green light may be seen. Note in Fig. 19-22*a* that a *cathode-light* shield is shown. It is a little metal cap that is placed over the end of the heated cathode so that no light but the green fluorescence may be seen.

However, you can see a complete circle of green light only when the target (which is always positive) and the ray-control electrode are at the same potential. Let's see why this is so. When the tube is connected as shown in Fig. 19-23, the ray-control electrode *RC* (connected to the triode plate P_t) is at the same potential as the target *TA*. So electrons will be attracted to it and to the target. However, let's see what happens when the ray-control electrode becomes less positive than the target.

To make the ray-control less positive than the target, we can insert a resistor between the triode plate and the target as in Fig. 19-

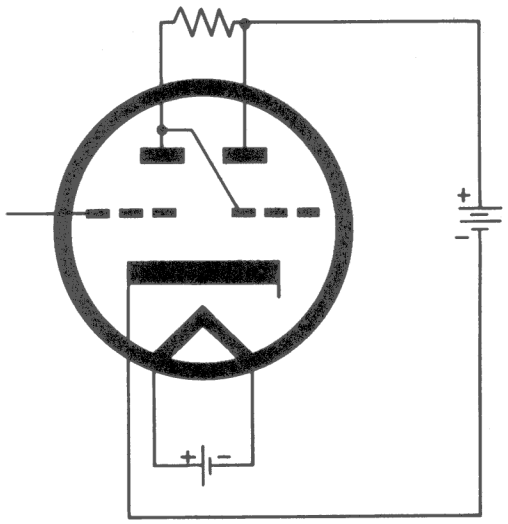


Fig. 19-24

24. Here the flow of current caused by electrons striking the triode plate and the ray-control electrode produces a current flow through the resistor and, thus, a voltage drop. This makes the ray-control electrode more negative (less positive) than the target. When this happens, the electrons racing toward the ray-control electrode bend away from it and travel on to the more positive (and more attractive) target. We say that the electrons *deflect* (change direction) and that they are *deflected* (caused to change direction) by the ray-control electrode. When electrons are so deflected, a part of the target behind the ray-control electrode receives no electrons and therefore does not glow with a green light. This portion of the target is in the electrical shadow of the ray-control electrode (Fig. 19-25). As the ray-control electrode potential becomes less positive, the electrons are deflected more sharply and the shadow angle widens (Fig. 19-26).

We use the triode as a d-c amplifier in order to produce differences in potential

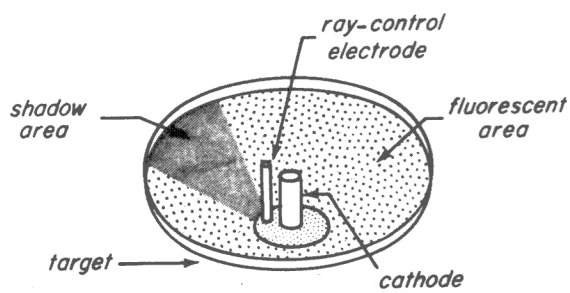


Fig. 19-25

Fig. 19-26

between the ray control and target. This only means that we apply a d-c voltage between the triode grid and the cathode in order to obtain a greater d-c change between the triode plate (connected to the ray control) and the cathode. The schematic diagram (Fig. 19-27) shows a variable d-c supply applied between the grid and cathode. As you learned in the early part of this lesson, plate current rises as the grid becomes less negative, and falls as the grid voltage becomes more negative. Finally, a point is reached (cutoff) where no plate current flows at all. Let's see what effect these changes in plate current have on the shadow area of the target. When high plate current flows, a large voltage drop appears across the resistor and makes the ray-control voltage much less positive than the target voltage, so widens the shadow angle. When the plate current is low, producing a low voltage drop across the resistor, the ray-control voltage is only slightly less positive than the target voltage, so the shadow angle narrows. When cutoff is reached and no plate current flows, no voltage drop appears across the resistor,

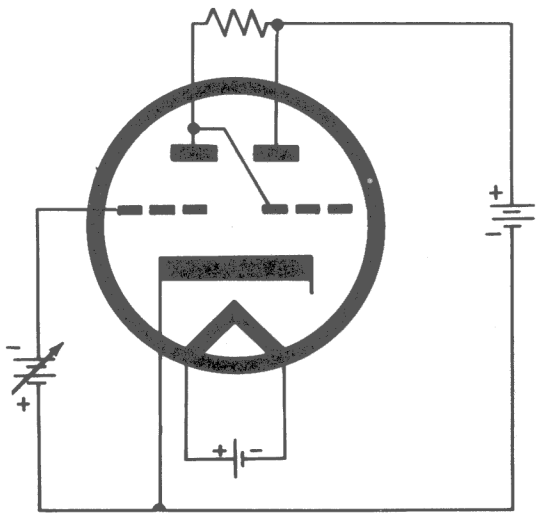


Fig. 19-27

and the shadow angle narrows to a thin line, which represents the minimum shadow of the ray-control electrode.

In some practical applications of the electron-ray tubes, circuits are designed so that the shadow angle is minimum when the circuits are adjusted to the desired point. In other cases, circuits are designed that call for the widest shadow angle for proper circuit adjustment. In later lessons, particularly those dealing with tuned circuits, you will learn more about practical electron-ray tube circuits.

APPENDIX A – ELECTRON-TUBE LETTER SYMBOLS

The letter symbols below, which are used to represent the different voltages and currents involved in electron tubes and electron tube circuits, are in agreement with those given by the Institute of Radio Engineers and are used by most standard textbooks.

Each symbol consists of a letter and a subscript. The letter identifies a voltage or current, and the subscript identifies an electrode of the tube concerned. The letters E and e are used to represent voltages, while the letters I and i are used to represent currents. Capital letters are used to stand for either *steady* voltages or currents, or the *rms* value of a-c voltages and currents. Lower case letters stand for *instantaneous* values of a varying signal voltage or current.

All subscripts are lower case. Only a few subscripts are used: b, p, c, and g. The subscripts b and p both mean that the voltage or current applies to the plate circuit. The b subscript is used to represent the *total* value (d.c. plus a.c.) from plate to cathode; the p subscript is used to represent the value of a.c. or signal component between plate and cathode. The remaining subscripts c and g both apply to the grid circuit; the c subscript is applied to the *total* value (d.c. plus a.c.) between the grid and cathode of a tube, while the g subscript is applied to the value of the a.c. or signal component between grid and cathode.

The use of the subscripts b and c for plate and grid stems from the early days of radio, when the plate supply battery was called the "B" battery, and the grid supply battery was called the "C" battery. The a-c subscripts p and g are the first letters of the words plate and grid, respectively.

Double subscripts are used to indicate sources, such as the B voltage supply, which is designated E_{bb}, and they are used only with capital letters.

Examples of the use of these symbols are given in the following tabulation and shown in the figure below.

e_b, i_b, e_c = instantaneous total value of voltage (or current) from plate (or grid) to cathode.

e_p, i_p, e_g = instantaneous value of *signal component* of plate (or grid) voltage (or current)

E_b, I_b, E_c = d-c voltage (or current) from plate (or grid) to cathode with no input signal

E_p, I_p, E_g = effective (rms) value of the *signal component* of the plate (or grid) voltage (or current)

The relationship between the various symbols can also be further illustrated by the following equations:

$$e_b = E_b + e_p$$

$$i_b = I_b + i_p$$

$$e_c = E_c + e_g$$

$$E_b = E_{bb} - I_b R_L$$